Utility of cone-beam CT imaging for the determination of feeding vessels during arterial embolization for massive hemoptysis

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PURPOSE

We aimed to evaluate the role of cone-beam computed tomography (CT) performed as an adjunct to angiography for the determination of feeding vessels responsible for bleeding during arterial embolization for massive hemoptysis.

METHODS

In this retrospective study, 23 patients with massive hemoptysis who underwent cone-beam CT evaluation prior to arterial embolization from December 2014 to December 2017 were included. During the angiographic session, two interventional radiologists selected the possible feeding vessels that were likely to supply the bleeding target lesions. Contrast-enhanced cone-beam CT was performed at the indefinite feeding arteries as an adjunct to angiography to determine whether the artery was a real feeding vessel, based on whether the target lesion was detected in the perfused territory of the study artery on images.

RESULTS

Selective cone-beam CT was successfully performed in 21 patients, at 26 possible feeding vessels that were detected by selective angiography. Cone-beam CT determined the feeding vessel in 24 arteries (92.3%) in 19 patients (90.5%). As a result of cone-beam CT findings, 16 of 24 study arteries were judged as definitively not feeding vessels (66.7%) and the remaining 8 study arteries were judged as definitively feeding vessels (33.3%). In 2 of 26 study arteries, cone-beam CT could not determine the feeding vessel (7.7%).

CONCLUSION

Cone-beam CT performed as an adjunctive technique to angiography is sufficient to provide adequate information for confident determination of the feeding vessel, which is essential for the operators to perform accurate embolization during arterial embolization for massive hemoptysis.

E tiological causes of hemoptysis include pulmonary tuberculosis, aspergillosis, chronic bronchitis, bronchiectasis, lung cancer, and cystic fibrosis. Massive hemoptysis is defined as more than 300 mL blood loss from hemoptysis over a 24-hour period. Transarterial embolization has become an established alternative method for controlling massive hemoptysis (1–3).

In patients suffering from massive hemoptysis, the dominant feeding vessels supplying the bleeding lesion (also termed bleeding vessels) may arise from both the bronchial and nonbronchial systemic arteries (3, 4). Considering the variant vascular anatomy of bronchial and nonbronchial systemic arteries, one challenging aspect of transarterial embolization for hemoptysis is to precisely identify the feeding vessels supplying the bleeding lesion, which is essential for the operators to perform accurate embolization and avoid unnecessary embolization.

Digital subtraction angiography (DSA) is the main imaging modality used during arterial embolization for massive hemoptysis. The abnormal angiographic signs that support the diagnosis of feeding vessels responsible for bleeding include contrast extravasation into the bronchial lumen, arterial enlargement, hypervascularity, tortuosity, vascular aneurysm/pseudoaneurysm, vessel cut off, and bronchial artery to pulmonary artery or vein shunting (2, 4–7).

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You may cite this article as: He G, Li T, Tang J, Zhang G. Utility of cone-beam CT imaging for the determination of feeding vessels during arterial embolization for massive hemoptysis. Diagn Interv Radiol 2018; 24:372–377.

As also evident in our experience, although some catheterized arteries demonstrate the abnormal angiographic sign of suspected contrast extravasation or hypervascularity, it is difficult to determine whether they are real feeding vessels based on single planar angiography images due to the imaging superimpositions, low soft-tissue attenuation resolution, or insufficient lesion vascularity (8, 9).

With the ability to provide volumetric tomographic images with high soft-tissue attenuation resolution over angiography, cone-beam computed tomography (CT) technique has been used widely for the detection of tumors and feeding branches in interventional radiology. As previously reported, the use of intraprocedural cone-beam CT revealed better diagnostic performance than angiography in identifying tumor-feeding branches (9). In the present study, we performed intraprocedural cone-beam CT as an adjunct to angiography, and we aimed to evaluate the role of cone-beam CT performed for the determination of feeding vessels supplying the bleeding lesions during emergent arterial embolization for massive hemoptysis.

Methods

Study population

This retrospective study was approved by the institutional review board and written informed consent was obtained from each patient or his/her family. From December 2014 to December 2017, 38 consecutive patients who experienced massive hemoptysis were referred for transarterial embolization emergently in our hospital. Twenty-three of the 38 patients (60.5%) who underwent intraprocedural cone-beam CT evaluation prior to arterial embolization were included in the analysis. Baseline characteristics of the included patients were summarized in the Table.

Main points

- One challenging aspect of transarterial embolization for massive hemoptysis is to precisely identify the feeding vessels supplying the bleeding lesion.

- It is difficult to determine whether the possible feeding vessels are real feeding vessels based on single planar angiography images alone.

- Cone-beam CT is sufficient to provide adequate information for confident determination of the feeding vessel during arterial embolization for massive hemoptysis.

All 23 patients were hospitalized. The coagulation profile and complete blood count of each patient were obtained. Eight hemodynamically unstable patients received blood component and fluid transfusion, and 5 patients with coagulopathy (international normalized ratio [INR] greater than 1.5) were corrected with fresh frozen plasma transfusion before the transarterial embolization. Besides, all patients underwent chest CT to localize the bleeding lesion (i.e., the target lesion) prior to transarterial treatment.

Angiography technique and embolization

Patients underwent transcatheter angiography and arterial embolization in an interventional suite equipped with the cone-beam CT option (Artis Zee; Siemens Medical) with continuous hemodynamic monitoring. All the interventional procedures were performed by two interventional radiologists with 11 and 19 years of experience in interventional radiology, respectively.

A transfemoral access was obtained with a 4 F micropuncture system (Cook Medical) via a modified Seldinger puncture technique under local anesthesia, and a 4 F introducer was placed.

First, an initial descending thoracic aortogram with the use of nonionic iodinated contrast medium (Iodixanol; GE Healthcare) was performed to delineate both bronchial and nonbronchial systemic arteries associated with the bleeding. Subsequently, according to the location of the target lesion, the bronchial arteries were selectively catheterized using 4 F Cobra (Cook Medical) or Simmons catheter (Cordis, Johnson & Johnson Medical), and following angiography was performed to localize the bleeding site.

A microcatheter (Progreat 2.7 F, Terumo or Stride 2.6 F Asahi Intecc) was used for selective catheterization when needed. In some cases, bleeding sites were supplied by nonbronchial systemic arteries/collaterals, which included branches of the internal mammary artery, thyrocervical trunk, inferior phrenic artery, subclavian artery, axillary artery, extrathoracic artery, and superior intercostals. Thus, selective catheterizations and angiographies of the aforementioned nonbronchial systemic arteries were also obtained when needed. A radial artery access was necessary when there was an acute angulation at the origin of the artery to be catheterized.

We selectively catheterized and performed angiography at all arteries that maybe feeding vessels prior to embolization. The direct abnormal angiographic sign that supported the diagnosis of feeding vessel responsible for bleeding was the visualization of definite extravasation of contrast medium into the bronchial lumen. Definite contrast extravasation is defined as contrast medium outside the arterial wall that persist into the venous phase. The indirect abnormal angiographic signs that supported the diagnosis of feeding vessels included arterial enlargement, hypervascularity, tortuosity, aneurysms or pseudoaneurysms, vessel cut off and bronchial artery to pulmonary artery or vein shunting (Fig. 1). The subsequent selective embolization of the feeding vessels was performed under fluoroscopic guidance with embolic agents to the point of flow stasis.

Cone-beam CT protocol

During the angiographic session, a catheterized artery was defined as a possible

Table. Baseline patient characteristics	
Patient characteristic	Value
Age (years), mean (range)	61.8 (45–82)
Sex, (M:F)	15:8
Cause of hemoptysis, n	
Pulmonary tuberculosis	10
Bronchiectasis	6
Lung cancer	5
Aspergillosis	2
Blood loss from hemoptysis in 24 hours (mL), mean (range)	780 (360–2030)

feeding vessel when it was characterized by suspected contrast extravasation or hypervascularity in the absence of other abnormal angiographic signs. It was not possible to determine whether a possible feeding vessel was a real feeding vessel based on angiography images due to the absence of aforementioned typical abnormal angiographic signs. Selective cone-beam CT was performed when the two interventional radiologists simultaneously confirmed the catheterized artery was a possible feeding vessel. Selective cone-beam CT was performed at the possible feeding vessel with 6–12 mL of 100% contrast medium injected automatically at a rate of 2–4 mL/s according to the vessel diameter for 3 s with an imaging delay of 5 s. For each cone-beam CT scan, images were acquired during 8 s acquisition time covering a 208° clockwise rotation. Multiplanar reformation images
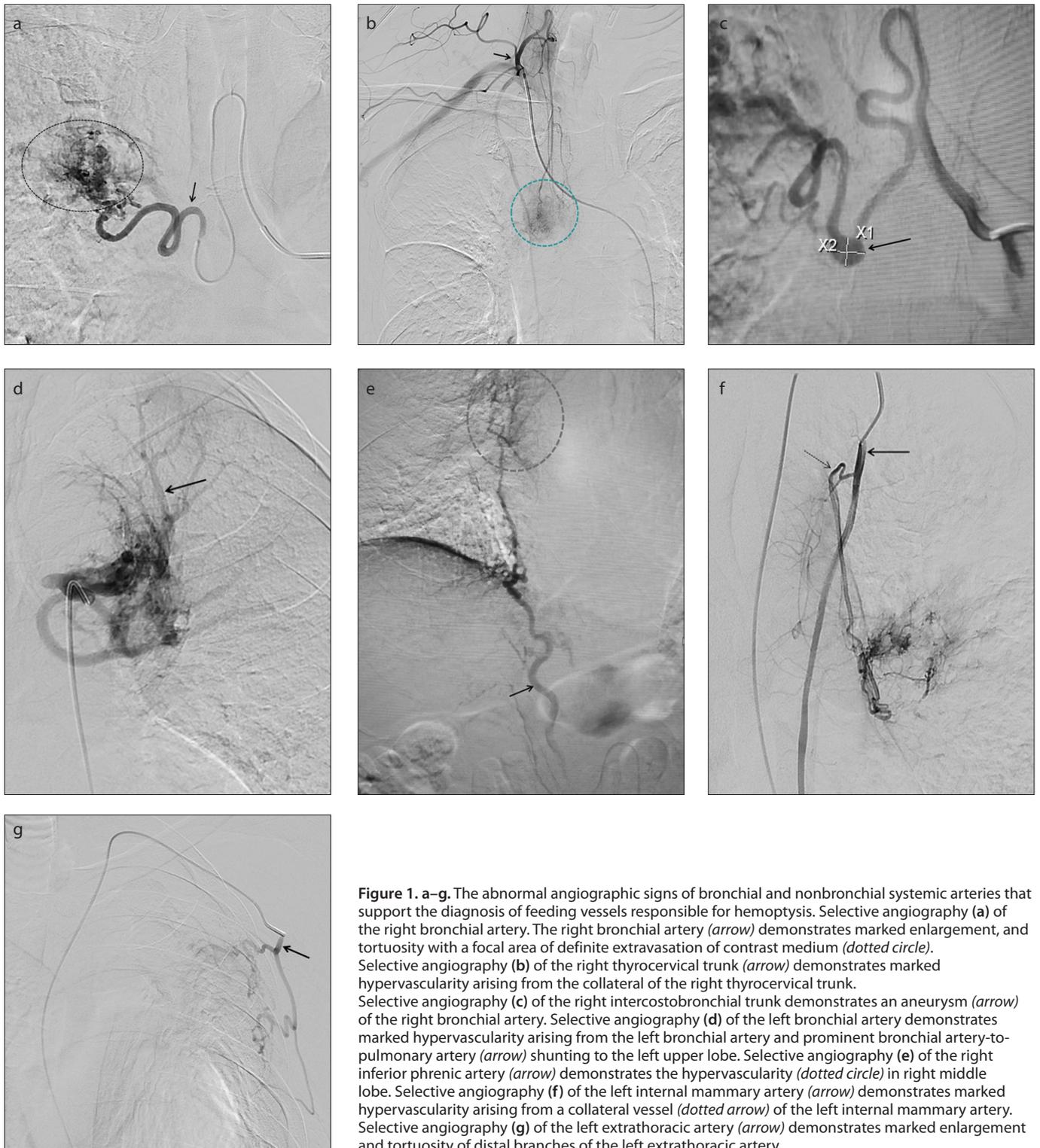

Figure 1. a–g. The abnormal angiographic signs of bronchial and nonbronchial systemic arteries that support the diagnosis of feeding vessels responsible for hemoptysis. Selective angiography **(a)** of the right bronchial artery. The right bronchial artery *(arrow)* demonstrates marked enlargement, and tortuosity with a focal area of definite extravasation of contrast medium *(dotted circle)*.
Selective angiography **(b)** of the right thyrocervical trunk *(arrow)* demonstrates marked hypervascularity arising from the collateral of the right thyrocervical trunk.
Selective angiography **(c)** of the right intercostobronchial trunk demonstrates an aneurysm *(arrow)* of the right bronchial artery. Selective angiography **(d)** of the left bronchial artery demonstrates marked hypervascularity arising from the left bronchial artery and prominent bronchial artery-to-pulmonary artery *(arrow)* shunting to the left upper lobe. Selective angiography **(e)** of the right inferior phrenic artery *(arrow)* demonstrates the hypervascularity *(dotted circle)* in right middle lobe. Selective angiography **(f)** of the left internal mammary artery *(arrow)* demonstrates marked hypervascularity arising from a collateral vessel *(dotted arrow)* of the left internal mammary artery. Selective angiography **(g)** of the left extrathoracic artery *(arrow)* demonstrates marked enlargement and tortuosity of distal branches of the left extrathoracic artery.

were reviewed by using 5 mm thick slices, and three-dimensional visualization was obtained on a dedicated workstation (Leonardo with DynaCT; Siemens).

Image analysis criteria

Two interventional radiologists independently viewed the cone-beam CT images and corresponding preinterventional chest CT images to confirm: (*i*) the exact location of the target lesion on cone-beam CT images by comparison with the preprocedural chest CT images in the corresponding viewing plane, (*ii*) the perfused territory of the study artery on cone-beam CT images.

The two interventional radiologists independently evaluated each study artery with a uniform diagnostic criterion as follows: the study artery was judged as definitely a feeding vessel or definitely not a feeding vessel based on whether the target lesion was detected in the perfused territory on cone-beam CT images.

In case of disagreement between the two interventional radiologists, the relevant images were re-evaluated by a third independent interventional radiologist (with 15 years of experience in vascular and interventional radiology) to obtain a consensus. Whether to perform embolization at the possible feeding vessel was on the basis of the cone-beam CT findings as follows: (*i*) embolization was performed at the possible feeding vessel that was judged as definitely a feeding vessel by cone-beam CT acquisitions, (*ii*) embolization was not performed at the possible feeding vessel that was judged as definitely not a feeding vessel by cone-beam CT acquisitions, (*iii*) embolization was performed at the possible feeding vessel that was indeterminate at cone-beam CT.

Results

A total of 28 possible feeding vessels in 23 patients were detected by selective angiography. The number of possible feeding vessels selected per patient was one in 18 patients and two in 5 patients.

Selective cone-beam CT was performed for 28 study arteries with a total of 28 cone-beam CT acquisitions. Two cone-beam CT acquisitions were excluded because of poor image quality caused by inadequate breath holding in two patients. Therefore, 26 (92.9%) successful cone-beam CT acquisitions of 21 (91.3%) patients were included and reviewed. Cone-beam CT allowed for

the determination of feeding vessels in most of the study arteries. Cone-beam CT determined the feeding vessel in 24 of 26 study arteries (92.3%), in 19 of 21 patients (90.5%). As a result, 16 of 24 study arteries (66.7%) were judged as definitely not feeding vessels (Fig. 2), and the remaining 8 study arteries (33.3%) were judged as definitely feeding vessels (Fig. 3). There were only two study arteries (7.7%, 2/26) in which cone-beam CT did not allow for the determination of the feeding vessel due to the failure in confirming the relationship between the target lesion and the perfused territory.

According to our embolization protocol, embolization was performed at the 8 definitely feeding vessels as judged by the cone-beam CT acquisitions and two possible feeding vessels that were indeterminate at cone-beam CT. Embolization was not performed at the 16 definitely not feeding vessels as judged by the cone-beam CT acquisitions.

Discussion

In our experience with arterial embolization for massive hemoptysis, most of the patients received selective embolization in
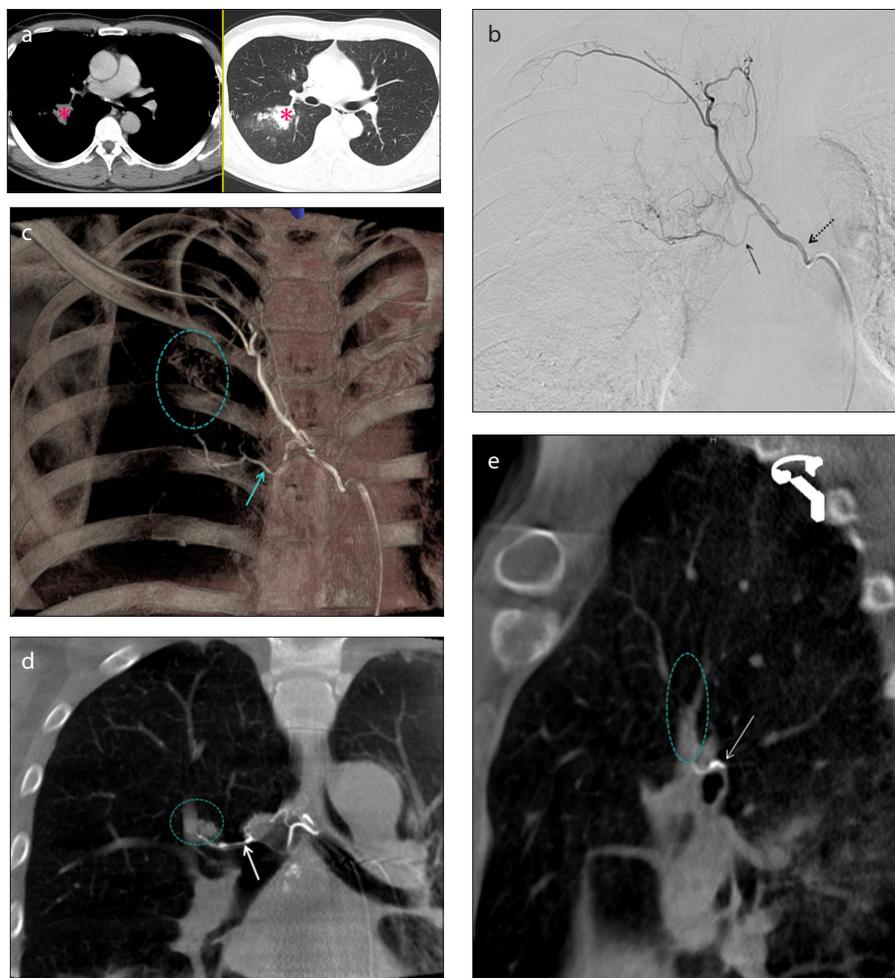

Figure 2. a–e. Preprocedural and intraprocedural images of a 56-year-old male patient suffering from a massive hemoptysis secondary to pulmonary bronchiectasis undergoing arterial embolization. Preprocedural axial chest CT scans **(a)** including lung and soft tissue windowing images demonstrate a mass *(asterisk)* located in the right lower lobe. Angiography image **(b)** of the right intercostobronchial trunk *(dotted arrow)* demonstrates suspected hypervascularity arising from the right superior bronchial artery *(arrow)*, which was determined by two interventional radiologists to be a possible feeding vessel responsible for hemoptysis. Three-dimensional volume-rendered image **(c)** from contrast-enhanced cone-beam CT of the intercostobronchial trunk demonstrates perfused territory *(dotted circle)* of the right superior bronchial artery *(arrow)* without the target lesion. The corresponding contrast-enhanced coronal cone-beam CT image **(d)** demonstrates perfused territory *(dotted circle)* of the right superior bronchial artery *(arrow)* without the target lesion. The corresponding contrast-enhanced sagittal cone-beam CT image **(e)** demonstrates perfused territory *(dotted circle)* of the right superior bronchial artery *(arrow)* without the target lesion.
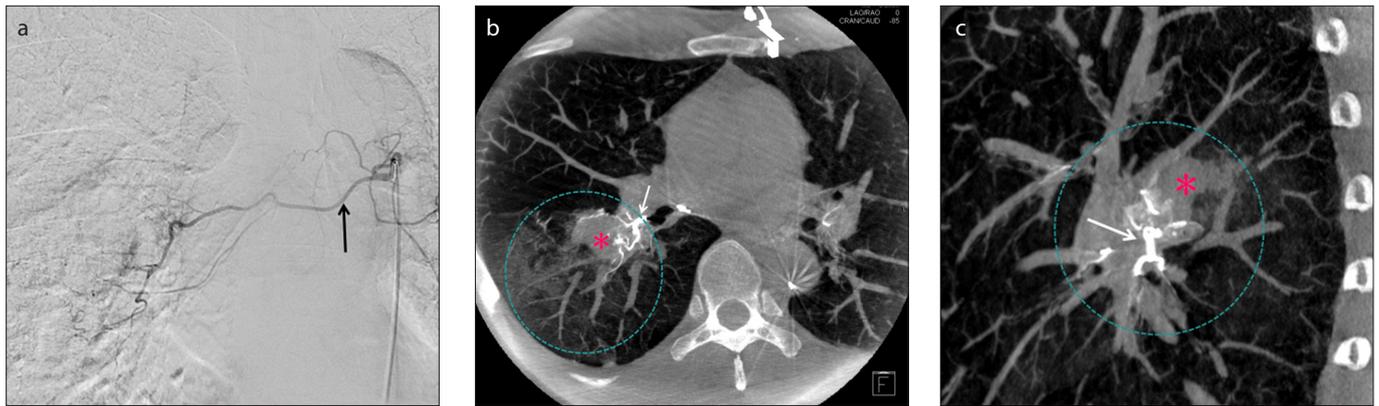
Figure 3. a–c. Intraprocedural images of a 56-year-old male patient (the same patient as in Fig. 2). Selective angiography **(a)** of the right inferior bronchial artery *(arrow)* demonstrates suspected hypervascularity arising from the right inferior bronchial artery which is likely to be a feeding vessel responsible for hemoptysis. The corresponding contrast-enhanced axial cone-beam CT image **(b)** of the right inferior bronchial artery *(arrow)* demonstrates the target lesion *(asterisk)* in the perfused territory *(dotted circle)* of the right inferior bronchial artery. The corresponding contrast-enhanced sagittal cone-beam CT image **(c)** of the right inferior bronchial artery *(arrow)* demonstrates the target lesion *(asterisk)* in the perfused territory *(dotted circle)* of the right inferior bronchial artery.

multiple feeding vessels including bronchial and nonbronchial systemic arteries. Therefore, precise identification of the feeding vessels is essential for the operators to perform accurate embolization, and avoid unnecessary embolization to decrease the risk of embolization-related complications including tissue ischemia or infarction, and organ dysfunction.

In previous studies, contrast-enhanced cone-beam CT had been used for anatomic diagnosis and treatment planning prior to arterial embolization, because it had the ability to provide intraprocedural three-dimensional images including enhanced vascular and soft-tissue details, which helped clarify the variant vascular anatomy that was indeterminate at conventional angiography (8, 9).

In the present study, intraprocedural cone-beam CT was performed to delineate the exact target lesion, and confirm the perfused territory of the study artery with contrast medium selective injection.

On the one hand, with the ability to provide detailed soft-tissue information, cone-beam CT is useful when the target lesion that is invisible or inadequate to visualize at angiography but that can be identified with preprocedural CT images. Intraprocedural cone-beam CT is able to provide multiplanar "CT-like" images compared with single planar angiography, which enable the users to confidently confirm the accurate location of the target lesion on cone-beam CT images by comparison with preprocedural CT images in the corresponding viewing plane (8, 9, 10–13).

On the other hand, cone-beam CT images acquired by injecting contrast medium into the target artery allow the users to visualize the vascular distribution of the selected vessel and its corresponding perfused territory within a region of interest, and "page through" different planes of cone-beam CT images to confirm the accurate correlation of perfused territory with the adjacent soft-tissue structures (10). In the present study, when selective contrast-enhanced cone-beam CT was performed, contrast medium without dilution and an imaging delay of 5 s were used, as the clear visualization of arterial anatomy and parenchymal enhancement were both desired. As a result, selective cone-beam CT images could demonstrate the study artery and reveal the anatomic relationship between the target lesion and its adjacent soft-tissue structures, which enabled the interventional radiologists to confirm whether the target lesion was in the perfused territory of the study artery.

In the present study, a catheterized artery was defined as a possible feeding vessel when it was characterized by abnormal angiographic signs including suspected contrast extravasation or hypervascularity. As a result of cone-beam CT, 66.7% of possible feeding vessels were judged as definitely not feeding vessels. One reason for the high ratio of vessels judged as definitely not feeding vessels may be that some abnormal angiographic signs might be respiratory motion artifacts. Another reason may be that conventional angiography provided lower soft-tissue attenuation resolution than cone-beam CT.

It should be noted that the precise delineation of the target lesion using cone-beam CT is paramount for the interventional radiologists to determine whether the study artery is a feeding vessel. The cone-beam CT technique used in the present study for the determination of feeding vessels is not suitable for cases such as cryptogenic hemoptysis and diffuse aspergillosis, in which preprocedural CT is unable to demonstrate or confirm the exact target lesions associated with hemoptysis.

The disadvantages of the incorporating cone-beam CT into the treatment planning included more intraprocedural contrast medium used and respiratory motion artifacts caused by inadequate breath holding sometimes interfering with the image interpretation. Especially, adequate breath holding was sometimes difficult for patients with massive hemoptysis. In the present study, two cone-beam CT acquisitions in two patients were excluded because of poor image quality caused by inadequate breath holding.

The present study has some limitations. First, a reference diagnostic standard was not used for the identification of feeding vessels. Furthermore, cone-beam CT was only performed at the possible feeding vessels selected by two interventional radiologists. Therefore, a comparative analysis of diagnostic accuracy between angiography and cone-beam CT was not undertaken. The decision to perform embolization at the possible feeding vessels was based on the cone-beam CT findings. Second, there may have been potential selection bias due to the retrospective nature of the present study. Third, duration of the procedures and the cumulative patient radiation doses

were not measured because embolization procedures were performed emergently; therefore, we could determine the impact of using cone-beam CT on procedural duration and radiation doses. Fourth, CT angiography before embolization is useful to decide the feeding vessels. One shortcoming of the present study is the absence of pre-procedural CT angiography images. This is because the patients with life-threatening massive hemoptysis need urgent embolization procedures.

In conclusion, cone-beam CT performed as an adjunct to angiography is sufficient to provide adequate information for confident determination of the feeding vessel, which is essential for the operators to perform accurate embolization during arterial embolization for massive hemoptysis.

Conflict of interest disclosure
The authors declared no conflicts of interest.

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